Express Mail #
EL 990504057 US

A METHOD AND SYSTEM FOR TURNING ON AN OPTICAL RADIATION SOURCE

This application is a continuation in part of Application No. 10/388,566 filed on March 14, 2003.

BACKGROUND OF THE INVENTION

1. Field of the Invention

Commercial wavelength division multiplex (WDM) systems, especially of the "dense" type (DWDM) provide high transmission capacity operating with channel spacings of 50-100 GHz.

2. Brief Description of Related Developments

In order to ensure the wavelength stability required for the optical source, real time control of the wavelength emitted is an essential feature to be provided (preferably together with automatic power and extinction ratio control) in any of the transmitter modules included in a WDM/DWDM arrangement.

The modules in question generally include a laser diode as the optical source emitting signal light together with a so-called "wavelength locker" arrangement - including a wavelength selective optical component and photodiodes to detect any wavelength and power variations in the laser source, a laser driver to bias the laser diode and a temperature conditioning element such as a thermoelectric cooler (TEC) - typically a Peltier element - for controlling the temperature of the laser diode together with its drive circuit.

One of the most critical phases of operation of such a module is the start-up phase.

During the start-up phase, the optical source is turned on and, within the first few hundreds microseconds, its temperature may significantly change. The wavelength of the radiation emitted may consequently exceed the maximum allowed fluctuations, while the wavelength and power control systems usually associated with such a module (and intended essentially to ensure source stability during normal operation) may operate with different time constants during the start-up phase thus undesirably contributing to such fluctuations.

In fact wavelength stability of the optical source must be ensured also under these conditions, in order to avoid that undesired large fluctuations in the output wavelength of the radiation emitted by the module being turned-on may adversely affect performance in the adjacent channels.

Prior art arrangements providing for optical wavelength and/or power control using analogue techniques, such as disclosed e.g. in US-A-5 825 792 are not in a position to properly ensure such a strict wavelength control during the start-up phase. The same also applies to arrangements as disclosed e.g. in US-A -5 438 579 providing for fairly sophisticated wavelength stabilization against temperature-related variations.

Certain DWDM modules are also known in the art including optical switches or controlled attenuators to prevent light emission when the laser diode is turned on, so that the laser beam is emitted only after the undesired wavelength variations are dispensed with. The

main drawback of these arrangements lies in that additional elements (the optical switch or controlled attenuator) must be included in the module. Also, these additional devices may undesirably interfere with laser emission during normal operation.

SUMMARY OF THE INVENTION

The object of the present invention is thus to provide an optical wavelength and power control system wherein the drawbacks of the prior art are dispensed with and the final operation wavelength may be safely reached without exceeding the maximum allowed fluctuations.

According to the present invention, such an object is achieved by means of a method having the features called for in the claims which follow. The invention also relates to the corresponding system.

The method of the invention is particularly, yet not exclusively, adapted for use in a wavelength and power control system for an optical communication module including: a laser diode as the optical source; photosensitive elements such as photodiodes, at least one of which has associated therewith a wavelength selective optical component such an optical filter, to detect any wavelength/power variations in the laser diode; a laser driver to bias the laser diode and a temperature conditioning element, such as a thermoelectric cooler (TEC) based on the Peltier effect, for controlling the temperature of the laser diode with a corresponding drive circuit associated therewith.

In the case of an optical source comprised of a laser diode, as a first step, the diode junction is subject to preheating.

Such pre-heating preferably involves forcing a current through the laser diode, so that the laser diode is subject to self-heating by the current flowing through it. The intensity of this current is zero at the beginning and is subsequently increased until a minimum current value (IBias) is reached.

However, before forcing the current flow, the laser diode is brought to an initial temperature (TInitial) which is a function of the laser current (IBias), the final laser temperature (TWorking point) and a theoretical estimation of the working point laser current. This first preheating is preferably effected by using the TEC controller.

The optical power is then a gradually increased to reach the final optical power value. This process is started once of the minimum current (IBias) is reached and involves increasing the optical power starting from the value reached at the end of the previous phase (Pinitial) to reach the final optical power value (PWorking point) intended for regular operation.

Once the final optical power value (PWorking point) is reached and the temperature control target is updated to the final temperature value (TWorking point) the wavelength sensor is adapted to the give valid wavelength measurements, thus enabling the wavelength controller to reach the final wavelength target value (WWorking point). The wavelength controller is enabled while the temperature control is disabled and the temperature sensor is subsequently used as a temperature monitor only.

During normal operation, aging phenomena affect the laser diode that are compensated to maintain the operating point (optical power and wavelength) unchanged by automatically adjusting e.g. the thermoelectric cooler (TEC) temperature and the laser currents.

In the presently preferred embodiment, the solution of the invention further ensures that when the module is turned off and then turned on again, the new start-up sequence points to the right power and wavelength targets by taking into account the aging effects. This aging tracking procedure provides for the average values of the TEC temperature and laser current to be stored daily. In that way, if the module is turned off and then turned on again, the start-up sequence uses the updated values thus stored in order to reach the actual aging-compensated operating points.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described, by way of example only, with reference to the annexed drawings, wherein:

- Figure 1 is a block diagram of an optical module adapted to be operated according to the invention,

- Figure 2 is a flow diagram showing the start-up procedure of the invention,

- Figure 3 shows the typical time behaviours of the laser temperature, laser bias current and optical power in an optical module operated according to the invention, *and*

- Figure 4 shows the typical time behaviours of the laser temperature, laser bias and modulation currents and optical laser power in an optical module operated according to an alternative embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(s)

The arrangement shown in figure 1 essentially includes an optical source such as a laser beam source 1 mounted on a so-called Optical Sub-Assembly (OSA) together with first and second photosensitive elements 2 and 3 usually comprised of photodetectors such as photodiodes.

First photodiode 2 has associated therewith a wavelength-selective element 4. Element 4 may be comprised of an optical filter centered at a wavelength corresponding to the nominal emission wavelength of laser source 1.

The arrangement in question, currently referred to as a "wavelength locker" provides for photodiode 3, used as reference, to sample an unfiltered portion of the laser beam. Another portion of the laser beam is passed through optical filter 4 and caused to impinge onto photodiode 2.

The response (i.e. the photocurrent) of photodiode 2 is thus a function of the possible displacement/misalignment of the actual wavelength of the beam generated by laser source 1 with respect to its nominal wavelength.

Conversely, the response of photodiode 3 is indicative of the power emitted by laser source 1.

The arrangement in question is conventional in the art and does not require to be described in greater detail herein.

This also applies to the provision of elements or means permitting the wavelength and power of the radiation emitted by source 1 to be selectively controlled.

These currently include a thermoelectric cooler (TEC) such as a Peltier element (not shown) associated to laser source 1 and controlled via a line 5, thus permitting the laser temperature to be controlled and temperature-induced wavelength variations compensated.

Similarly, reference 6 designates a line adapted to convey a control signal of the laser source currents to enable selective control of the power emitted by source 1.

In the exemplary embodiment of the invention shown, the required control action of optical source 1 via the signals on lines 5 and 6 is effected as a function of the output signals of photodiodes 2 and 3 is effected by means of a micro-controller generally designated 7.

Being essentially a digital device, micro-controller 7 includes one or more analog-to-digital converters 71, 72 to convert into the digital format the output signals of photodiodes 2 and 3 as well as one or more digital-to-analog converters 73, 74 to convert the digital output signal of micro-controller 7 into analog signals adapted to be conveyed on lines 5 and 6.

The embodiment of the invention shown herein also includes a temperature sensor 8 sensitive to the external "ambience" temperature with respect to laser source 1 (and the respective Optical Sub-Assembly or OSA).

A further analog-to-digital-converter 75 is thus included in micro-controller 7 to convert the output signal of temperature sensor 8 to the digital format.

Essentially, DWDM transmitters including modules of the kind just described must ensure that the emitted light is always within valid wavelength limits. If the wavelength of the radiation emitted exceeds such limits, both the transmitted data are lost and also the adjacent DWDM channels are adversely affected.

For instance, in current DWDM systems, the emitted wavelength must be within ± 30GHz and ± 6GHz with respect to the nominal wavelength value during start-up and during normal operation, respectively.

The most significant source of wavelength variations are variations in the laser diode temperature. In fact, the wavelength of the radiation emitted is a function of the laser diode temperature. This physical phenomenon explains why DWDM modules use controlled thermoelectric coolers (TECs) such as Peltier elements to maintain the laser diode temperature as constant as possible.

When a laser diode is turned on, by causing an appreciable current flow through it, the diode junction temperature changes during the first microseconds due to the additional power to be dissipated. Even if temperature control is used, the temperature may still

change leading to large wavelength variations, e.g. in excess of 30GHz.

Essentially, the arrangement disclosed herein implements a sort of "soft" start-up procedure in order to limit the initial undesired wavelength variations in the optical radiation emitted by the laser source. In that way, the optical module is allowed to reach a predefined working point while avoiding the undesired initial wavelength variations currently encountered when the laser source is turned on.

When the module is turned on, the soft start-up procedure is executed in order to reach precise values for the optical power, wavelength and extinction ratio (i.e. the predefined working point) of the laser source, while taking into account the fact that the emitted wavelength must always remain within predefine limits.

In the presently preferred embodiment of the invention, the soft start-up procedure is performed within microcontroller 7 as a result of interaction of a finite state machine (FSM) and four control functions, namely i) temperature control, ii) power control, iii) wavelength control and iv) extinction ratio control.

A detailed description of these control functions is provided in a co-pending European patent application filed concurrently with this application.

The finite state machine generates commands to the various actuators/controllers (see lines 5 and 6 of figure 1) assigning to them different targets to be reached as a function of real-time measurements and theoretical estimations of the actual wavelength value.

Once the working point is reached, the soft start-up procedure is terminated and each control function is then operated under steady conditions with the aim of maintaining the working point of laser source 1 unchanged.

As explained in the foregoing, when laser source 1 is turned on, initial wavelength variations are generated due to the diode junctions being almost instantaneously heated. This physical phenomenon cannot be compensated by standard temperature control functions i.a. because junction heating takes place within the laser diode, whereby any temperature sensor associated to laser source is not able to properly sense and measure such heating immediately.

The solution disclosed herein provides for the diode junction to be subject to pre-heating as a result of two combined effects, namely i) initial heating to a first temperature Tinitial using the TEC as a heater (which is permitted by the reversibility of the Peltier effect), and ii) subsequent heating obtained by causing an under-threshold current to flow through the diode, thus causing the laser junction to be heated while still emitting negligible optical power.

In the embodiment shown herein, laser preheating is thus effected by a combined action of two effects.

Firstly, laser diode 1 is heated using the TEC controller; subsequently, the laser junction is further heated forcing an under-threshold current to flow trough the laser diode.

The laser junction is located inside the laser diode and the wavelength of the radiation emitted

depends on the junction temperature and not on the laser diode surface temperature.

The TEC temperature control brings the laser diode (the surface of laser diode) to a predefined temperature.

Consequently, this first heating action by itself may not be enough to ensure the required control of wavelength variations because when the laser is turned on a current will flow through it to generate further heating and the ensuing wavelength variations.

The laser junction is thus further heated by an under-threshold current so that, as a result of this further heating action, the laser junction is brought to a temperature that is equal to the laser diode external temperature plus the contribution of heating the junction.

As a result of the combined heating action described in the foregoing, laser diode 1 can be turned on (that is an over-threshold current can be caused to flow through laser diode 1) with a limited variation of the wavelength value.

The sequence of actions for laser preheating is thus the following.

The laser diode is brought to an initial temperature (Tinitial). This process is not instantaneous, so that a certain amount of time must be caused to lapse before the further heating action is started.

Such further heating action involves an under-threshold current being forced to pass through the laser diode.

This under-threshold current is preferably a "ramp" that begins with at zero current value (0mA) and is increased until a predefined value (Ibias).

Ibias is generally an over-threshold current, but several values before reaching it (Ix<Ibias) are under-threshold and allow heating the laser junction. When the ramp reaches the final value (Ibias) the laser is automatically turned on(Ibias>threshold current) and the laser generates a valid wavelength value.

To ensure this, the initial temperature Tinitial must be chosen in such a way that the laser diode generates the right wavelength value when it is turned on with a current Ibias. Thus Tinitial is a function of Ibias, the final temperature TWorking point and a theoretical estimation of the working point laser current.

At this point, the laser is turned on and generates a very low optical power (Pinitial).

Before reaching this point the Pinitial values is not known, so, when this point is reached, the Pinitial is measured and is gradually increased until reach its final value (Pfinal).

For each intermediate value of optical power, microcontroller 7 calculates a proper value of temperature, which is passed to the TEC temperature control in order to bring the laser diode to the calculated temperature.

Each temperature value is calculated in order to minimize the wavelength variation respect to the nominal value.

By referring to the flow diagram of figure 2, the soft start-up procedure referred to in the foregoing may be regarded as comprised of five basic phases, namely:

- pre-heating the laser diode junction,

- gradually increasing the optical power generated until the final optical power value reached,

- reaching the final wavelength value,

- reaching the final extinction ratio value, and

- reaching the final working point.

The process in question is adapted to be effected by microcontroller 7 by implementing a finite state machine (FSM) whose operation is based on seven states essentially corresponding to blocks 10 to 70 in the block diagram of figure 2.

States 10 and 20 correspond to the laser diode junction pre-heating phase. At the beginning of this phase, the finite state machine calculates in a step 101 the initial target temperature (TInitial) - and then turns on the temperature control function - step 102 - thus causing a current ramp to be generated and caused to flow through laser diode 1.

The current through laser source 1 is initially zero and then increases until a pre-defined minimum current value IBias is reached. Such initial current value(s) are under-threshold so that laser source 1 only emits very low optical power.

In the flow-diagram of figure 2, the steps corresponding to the laser diode current being enabled

and a ramp-shaped laser diode current being generated are designated 201 and 202, respectively.

Once the current IBias is reached, the power emitted by laser source 1 is measured (as a function of the signal generated by photodiode 3), and the corresponding power target is updated (in step 203) in order to cause the optical power generated by source 1 to grow gradually starting from the optical power level PInitial reached at the end of the previous phase.

The power control function is turned on in a step 204 and caused to track subsequent increasing power targets in order to generate a step-wise, staircase-like increase in the power emitted. For each increase step the finite state machine calculates a new temperature target in order to minimize wavelength variations.

The foregoing essentially corresponds to states 30 and 40 in the flow diagram of figure 2 where step 301 is the initial step of a routine that is repeated periodically. Such a routine includes the steps of increasing the power target by a calculated differential value (step 302) and updating the power target (step 303). Such a routine also includes a state 40 to calculate the temperature target in order to minimize wavelength errors (step 401) and updating the temperature target (step 402).

As a result of completing the last increase step the module reaches the final optical power value (PWorking point), while the temperature control target is updated to the final temperature value TWorking point.

At this point the wavelength sensor is able to give valid wavelength measurements and a state 50 is reached in the finite state machine to update the wavelength target value (step 501) and turning on the wavelength control function (step 502) by assigning to it the final wavelength target value WWorking point.

In order to enable the wavelength control function, the temperature controller function is disabled and during the subsequent phases the temperature sensor is used as a temperature monitor only.

Upon reaching a subsequent state 60, the power control function is turned off (step 601) while the extinction ratio control function is turned on (step 602).

For that purpose, the modulation current Imod of laser diode 1 is generated (in a manner known per se) allowing data transmission. During this phase the power control function is disabled for a short period of time (as indicated in step 601) in order to allow the laser driver electronics to supply the new bias and modulation currents IBias and IMod, respectively.

After this short intermission, the finite state machine evolves to a state 70 where the power control function is turned on again (step 301). Thereafter, the system evolves to final step 702 which marks the end of the start-up procedure.

At this point both the power and wavelength control functions are enabled and the module has reached the predefined working point. Also, the extinction ratio control function is enabled and the module is ready to transmit data.

During current operation of the module, at least one of the operating parameters corresponding to the working point of laser source 1 is stored in a memory associated with microcontroller 7, such as memory 9. The data in question are stored in terms of average data over a certain time basis (e.g. in the form of average values which are updated daily).

Such periodically updated information records the effect of aging phenomena of laser diode 1, thereby making it possible for the module to use such aging-compensated data during subsequent start-up phases possibly effected in case the module is turned off to be subsequently turned on.

Further details concerning both the extinction ratio control function and recording of aging-compensated data in memory 9 are provided in the co-pending application already referred to in the foregoing.

In figure 3, diagrams designated LT, LB and EL show the typical behaviour over time (abscissa scale) of laser temperature LT, laser bias current LB and optical power EL emitted by laser 1 during the soft start-up procedure described in the foregoing.

By referring also to figure 2, in the exemplary embodiment considered in figure 3, state 10 lasts about 8 seconds after the beginning (0 seconds) of the start-up procedure. State 20 reached thereafter is terminated about 12 seconds after the beginning of the start-up procedure. States 30 and 40 are activated about 12 seconds and terminated about 32 seconds after the beginning of the start-up procedure. State 50 is reached about 32 seconds from the beginning of the start up procedure to be left at about 38 seconds to

reach state 60. State 60 is terminated at about 39 seconds, when state 70 (steady state) is reached.

Figure 4 of the drawing refers to an optical module operating according to an alternative embodiment of the invention.

Specifically, figure 4 includes four diagrams, indicated a) to d), showing the exemplary typical time behaviour of:

- the laser temperature LT (diagram a),

- the laser bias current LB (diagram b),

- the laser modulation current LM (diagram c), and

- the optical laser power EL (diagram d)

in such an alternative embodiment.

All the diagrams in question refer to a common time scale (abscissa), the same applying a further schematic diagram, designated e) as a whole. Diagram e) shows the instants of activation of the temperature controller TC, the wavelength controller WC and the power controller PC are activated.

In the alternative embodiment to which figure 4 refers, the temperature LT of the optical source 1 is brought to a pre-heating temperature To before the optical source 1 is activated.

The optical source 1 is subsequently activated by increasing the bias current LB while the optical source temperature LT is brought to a target value designated Ttarget. Specifically, the bias current LB is increased to keep the laser emission frequency/wavelength as close as possible to the target (nominal) value.

When the temperature of the optical source reaches the target value Ttarget, the power EL associated with the laser emission EL is very close to the target value. The power controller PC is activated - see the lowest line in diagram e) of figure 4 - essentially when the laser source temperature LT and the laser power EL have reached their target values as shown in the diagrams a) and d) of figure 4.

At that point, or shortly thereafter - see the highest line in diagram e) of figure 4 - the temperature controller TC is de-activated and the wavelength controller WC activated.

The wavelength controller WC and the power controller PC thus control steady state operation of the laser source.

Those of skill in the art will promptly appreciate that the alternative mode of operation now disclosed in connection with figure 4 can be easily implemented by taking into account the additional information provided in the following on the basis of the disclosure already provided in connection with figures 1 to 3.

The main differences between the mode of operation shown in figure 3 (hereinafter, the "basic" mode of operation) and the mode of operation shown in figure 4 (hereinafter, the "alternative" mode of operation) are the following.

In the alternative mode, starting from the pre-heating condition - i.e. laser off, laser temperature equal to To - the laser temperature LT is changed from the pre-heating value (To) the target value (Target) continuously while the bias current LB is changed to

keep the laser emission frequency/wavelength as close as possible to the target (nominal) value.

Conversely, in the "basic" mode, the bias current LB is changed stepwise as shown in figure 3 and the temperature adjusted at any step.

The alternative start up procedure of figure 4 progresses slowly from the CW status (bias current LB only) to the modulated condition (bias current LB plus modulation current LM) with the power control on.

Conversely, in the "basic" procedure of figure 3, this process occurs quickly, with the power control off resulting in undesired transient effects in the laser power.

The alternative mode of figure 4 is advantageous in that the resulting start up procedure is faster due to the presence of one temperature transient only, in contrast with the various temperature transients of the procedure to which figure 3 refers. A continuous power on is thus achieved in the arrangement of figure 4.

This step is somewhat slower in the arrangement of figure 4 in comparison to the arrangement of figure 3. This effect is thoroughly counterbalanced by the power control, once activated, being maintained always on while in the "basic" mode of operation possible power transients may arise.

Also, by resorting to the arrangement of figure 4, the complete start up process is faster than in the case of the arrangement shown in figure 3.

Of course, the principles of the invention remaining the same, the details of construction and the embodiments may widely vary with respect to what has

been described and illustrated purely by way of example, without departing from the scope of the present invention as defined by the annexed claims. Also, it will be appreciated that terms such as "optical", "light", "photosensitive", and the like are used herein with the meaning currently allotted to those terms in fiber and integrated optics, being thus intended to apply to radiation including in addition to visible light e.g. also infrared and ultraviolet radiation. Finally, even though the invention was devised by paying specific attention to the possible use in connection with laser diodes, the optical source considered may not necessarily be a laser diode, the solution of the invention being adapted to be used also in association with other sources such as different types of laser sources.